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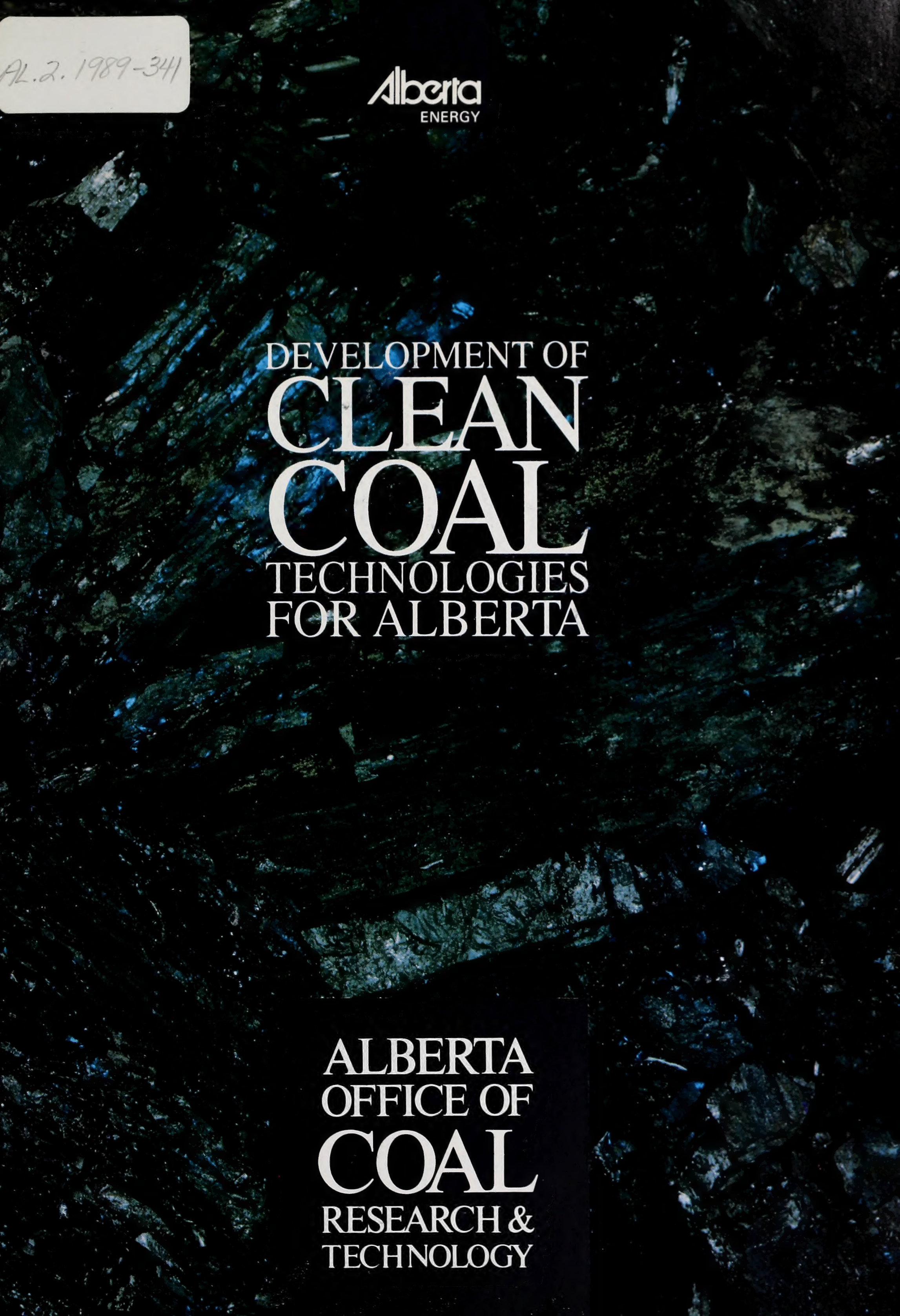

Alberta
ENERGY

DEVELOPMENT OF CLEAN COAL TECHNOLOGIES FOR ALBERTA

ALBERTA
OFFICE OF
COAL
RESEARCH &
TECHNOLOGY

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Alberta Research Council

AUG 23 1989

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ENERGY
Office of Coal Research
and Technology

Foreword

In 1984, the Alberta Office of Coal Research and Technology was established by the Minister of Energy and Natural Resources (now Energy). This was done to help Alberta's coal industry develop and implement new technologies that can be used to enhance the competitiveness of Alberta coals in international markets, minimize the environmental impact of the production or use of coal in Alberta, and establish new uses for Alberta coals.

During the ensuing years, many research projects were launched and much has been accomplished technically, but the coal industry, in general, still labours under the perception held by some people that coal combustion adversely affects air quality. While this may have been true in the past in some places, it has not been a problem in Alberta, principally because the concentrations of sulphur-containing species in Alberta coals are low. This means that current emission guidelines can be met when most of these coals are burned. This is one of the characteristics of Alberta coals that makes them highly desirable in Asian and central Canadian markets. Furthermore, developments now under way in Alberta and elsewhere should result in coal-use technologies that allow air quality to be affected even less when coal is burned.
This publication describes some of these efforts.

Introduction

Sometime during the first decade of the next century, coal may equal or surpass petroleum as the world's most utilized fuel. According to the International Energy Agency, coal demand by year 2005 in more than 20 member countries of the Organization for Economic Co-operation and Development (OECD) will increase 1.4 times the demand in 1985, and coal use as a percentage of total energy requirements will be approximately 30 per cent, the same as oil. Much of this growth is expected to occur in steam coal used to produce electricity. In the longer term, global coal production is expected to triple, and international trade in steam coal to rise by 10- to 15-fold.[1]

Growth such as this could contribute to renewed concern over the effects of air emissions from coal-burning plants, and it brings added urgency to the search for clean coal technologies that could help resolve the historical conflict between environmental protection and economic expansion.

The outcome of this conflict is vitally important to Alberta, because the province is the largest producer and the second largest exporter of coal in Canada. Alberta also has large reserves of coal that can contribute to the provincial economy for many years to come. Furthermore, the lifestyle enjoyed by Albertans is dependent on coal combustion because it is the source of more than 90 per cent of the electricity used in Alberta homes and industries. There are simple reasons for this. Coal is abundant, relatively inexpensive to mine, and produces low-cost electricity. Therefore, Alberta's coal industry affects virtually everyone in the province by contributing to low-cost living expenses and maintaining low industrial energy costs.

Alberta coals also have one other important advantage. They contain much less sulphur than coals from other coal-producing regions of the world. For example, the sulphur content of Alberta coals usually ranges from 0.2 to 0.7 per cent, whereas some coals from the eastern U.S. contain as much as 3.5 per cent sulphur. This makes Alberta coals attractive to central Canadian and export markets because sulphur-containing emissions from coal-burning plants meet current environmental guidelines without additional control equipment.

Furthermore, most of the other undesirable substances formed when coal is burned are expected to be removed by clean coal technologies now under development in Alberta and elsewhere. Also, certain clean coal technologies are beginning to address concerns about the ''Greenhouse Effect'' and the role that carbon dioxide (CO_2) plays in this phenomenon. Already, it is known that some clean coal technologies use fuels more efficiently than current coal combustion systems. This means less coal is needed and less CO_2 is produced in generating a given quantity of electricity.

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[1] Quickening the Pace in Clean Coal Technology, Electric Power Research Institute Journal, January/February 1989 (United States)

Emissions and Current Control Methods

The term "clean coal technology" refers to systems that produce fewer air pollutants than do conventional coal combustion methods used in various industrial processes or by utility companies to generate electricity. These emissions are in the form of solids (called particulates) and gases; the least desirable of the latter are sulphur oxides and nitrogen oxides. To understand the benefits from clean coal technologies, it is first necessary to be aware of some facts about air emissions from coal-burning operations.

On the subject of particulates[2], natural dust emissions are reported to exceed man-made sources on a world-wide basis, but the contribution from man-made sources can be significant on a local basis. Particulate emissions related to coal combustion can represent a significant source in countries relying on coal for power production.

Fly ash, which is formed when the mineral matter in coal is converted to ash, is largely responsible for the particulate matter present in emissions from coal-burning plants. Some ash is discharged from the bottom of the furnace and some leaves the furnace as particles suspended in the flue gas. Since the 1920s, devices known as electrostatic precipitators have been used successfully to recover most particles, but attention is being focused on particulates again because of claims that smaller particulates can cause health problems.

On a global scale, human activities account for 60 per cent of all emissions into the atmosphere of substances containing sulphur.[3] The remainder comes from sea spray, decay of organic materials and volcanoes. In industrialized areas, though, man's activities contribute up to 90 per cent of all sulphur emissions. Of this portion, 82 per cent is derived from combustion of fossil fuels. Fifty-six per cent results from coal burning and 26 per cent is derived from combustion of petroleum products. About 90 per cent of the sulphur released as a result of human activities is emitted as sulphur dioxide (SO_2).

Gaseous SO_2 emissions have increased 30 times since 1860 and are expected to increase 40 times by the year 2000.[4] They are suspected of having direct detrimental effects on the health of humans, and dry deposited SO_2 has damaged building materials. It is believed, however, that most of this damage occurred earlier this century.

In the atmosphere, SO_2 undergoes chemical conversion and reaction with other atmospheric species to form a variety of compounds, the most important being sulphuric acid and ammonium sulphate.

Besides sulphur dioxide, the other important gaseous emission produced by coal-burning plants is nitric oxide (NO).[5] It is subsequently oxidized in the atmosphere to nitrogen dioxide (NO_2), a more toxic substance. These two gases are generally considered together when they are collectively referred to as nitrogen oxides (NO_x).

Globally, combustion of fossil fuels produces about 40 per cent of NO_x emissions, whereas fossil fuel combustion appears to contribute 85 per cent of NO_x emissions to the atmosphere in North America. In the U.S., coal combustion provides about 32 per cent of NO_x emissions.

Another issue that has arisen lately concerns the presence of polycyclic aromatic hydrocarbons (PAH) in emissions from coal combustion operations. These substances, which are also known as polynuclear aromatic hydrocarbons (PNAs),[6] are emitted predominantly by human activities. Studies have shown that well-operated coal combustion plants produce quantities of PAH that are below levels of environmental concern. While PAH have been linked to cancer in humans, the evidence is not strong.

Although the basic attraction of coal remains its low cost and great abundance, the biggest obstacle to expansion of coal-fired power generation is the cost of environmental protection. It escalated rapidly during the 1970s and early 1980s. In the U.S., for example, as much as 40 per cent of the capital cost and 35 per cent of the operating costs of new plants can be accounted for by their pollution control systems.[1] These systems may also extract an energy penalty amounting to three to eight per cent of a plant's output.

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[2] Particulate Control for Coal Combustion, International Energy Agency, February 1988 (International).

[3] Acidic Deposition - Materials and Health Effects, International Energy Agency, December 1986 (International).

[4] Sulphates in the Atmosphere, International Energy Agency, November 1985 (International).

[5] Nitrogen Oxides from Coal Combustion - Abatement and Control, International Energy Agency, November 1980 (International).

[6] PAH from Coal Utilization - Emissions and Effects, International Energy Agency, December 1984 (International).

Classes of Clean Coal Technologies

Several technologies are being developed to make it possible to burn coal and satisfy more stringent emission standards than those used today. These clean coal technologies are either on the verge of becoming commercially available or are expected to be available by the year 2000.

Clean coal technologies may be divided into three classes: pre-combustion; during combustion; and post-combustion. Research is under way in Alberta on all three classes. The Alberta Office of Coal Research and Technology is providing some support for this research with funds from the Alberta/Canada Energy Resources Research Fund.

Pre-Combustion Technologies

The Alberta Office of Coal Research and Technology is involved in a number of coal research projects that contain elements related to lower emissions levels. For example, a major program has been under way since the late 1970s to produce liquid transportation fuels from coal. This work includes methods to lower the sulphur and nitrogen levels of the synthetic crude oils made from coals and from which transportation fuels are produced by refining. Various experiments have been, and are continuing to be, conducted to clean coal and remove certain components that ultimately produce emissions or particulates. In a process known as agglomeration, which has been studied for several years at the Alberta Research Council, most of the mineral matter, including certain sulphur compounds, is removed from coal. The resulting product represents a higher-energy fuel. Work has also been done to produce coal-water fuels that can replace fuel oil in power stations. The preparation of these is aided by improved coal-cleaning processes. All of these pre-combustion technologies represent potentially important steps toward clean coal combustion.

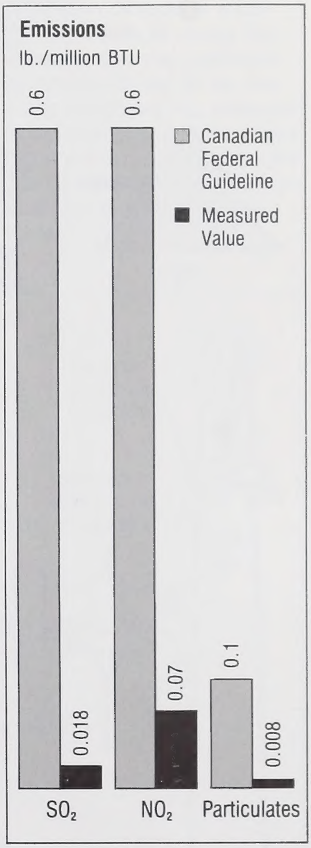
Combustion Technologies

Coal Gasification

The most promising example of combustion-type clean coal technology is called integrated gasification combined cycle (IGCC) power generation. It couples an old technology (coal gasification) with a new technology (combined cycle power plants) to convert coal into a gas composed mainly of hydrogen, carbon monoxide and carbon dioxide. This gas is then used to operate turbines and produce electricity. Sulphur in the coal is converted in the gasifier to hydrogen sulphide and a small quantity of carbonyl sulphide. The gas mixture is cooled and the sulphur gases are removed from the gas stream, together with particulates, before the gas is burned. This allows high removal efficiencies to be accomplished at moderate cost. The gas is then burned in a gas turbine to produce electricity.

The hot gas-turbine exhaust gases are used to generate steam in a heat recovery boiler. This, together with steam generated in cooling the gas after gasification, is used to generate additional power in a steam turbine.

The concept has several advantages. Environmentally, the system produces very low levels of gaseous emissions, some of which are significantly below current and projected emission control guidelines. For example, the following data were obtained from a demonstration-scale IGCC plant operating in California:[7]



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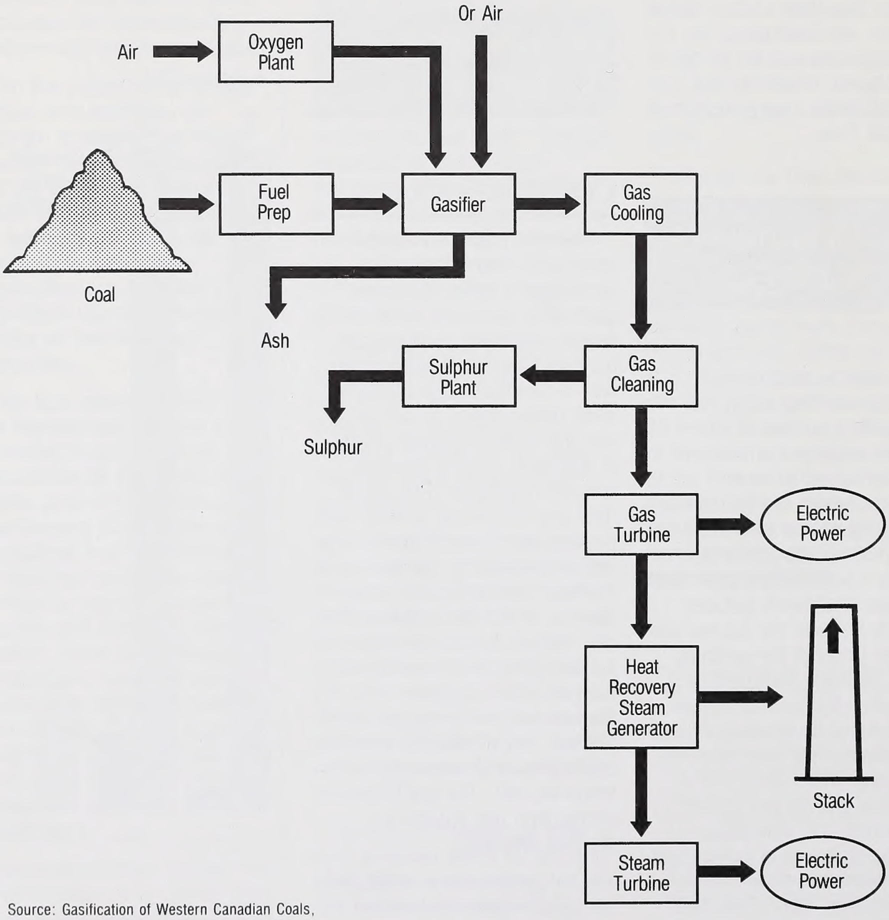
[7] Developments in Coal Technology - A Review, Monenco Consultants Limited, April 1988 (International).

Technology exists to remove virtually all polycyclic aromatic hydrocarbons from coal gasification plants. As well, solid waste from the plant is in the form of a glassy, inert slag that has been classified as non-toxic in California. Also, water requirements are significantly lower than for conventional power plants.

Other advantages of IGCC systems are:

- IGCC plants can be as much as 10 per cent more efficient than conventional plants, leading to lower carbon dioxide emissions;
- mature IGCC plants are said to have the same capital requirements as conventional plants. When combined with higher efficiency, this means lower-cost electricity;
- IGCC plants can be modular and comprise parallel trains. This means smaller plants in the 100 to 200 MW range can be built economically; and
- it is expected that modular plants will readily be available.

IGCC System Schematic



Source: Gasification of Western Canadian Coals, TransAlta Utilities Corporation, January 1987

IGCC technology is actively being pursued in the U.S., Japan and Europe, and several demonstration plants are in operation or being planned.

Alberta is participating in the Canadian Coal Gasification Technical Committee,[8] which was formed to oversee and fund coal gasification research and development projects comprising a multi-year program. The objectives of this program are:

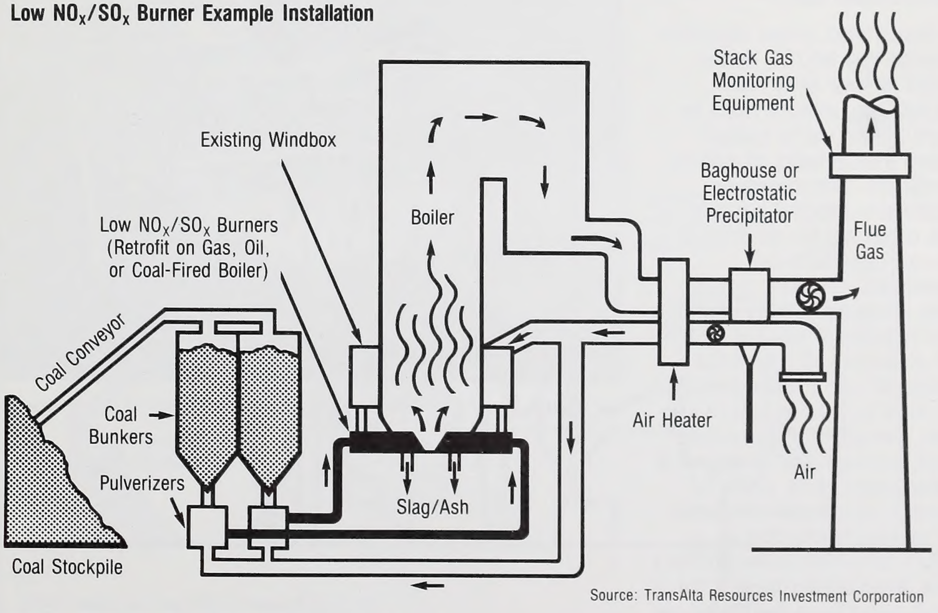
- to design and build a 100 MW (electrical) prototype demonstration IGCC plant in Canada by 1994;
- to establish and standardize coal gasification testing methods for Canadian laboratories; and
- to facilitate performance evaluations of Canadian coals in various coal gasification technologies.

Thus far, more than 10 coal gasification projects have been funded in part by the Alberta Office of Coal Research and Technology. A signficant portion of this work is being carried out at the Alberta Research Council, while Alberta coal producers and users have been conducting economic feasibility studies.

Low NO_x/SO_x Burner

The TransAlta Low NO_x/SO_x Burner (LNSB), is another example of combustion-type clean coal technology. The burner is a multi-stage, slagging-type combustor intended to control NO_x and SO_x simultaneously. It was developed initially by Rockwell International in the United States, but the technology is now owned by TransAlta Resources Investment Corporation of Calgary. The LNSB uses advanced combustion concepts in a cost-effective manner to reduce SO_x emissions from coal combustion by between 70 and 90 per cent. It also suppresses NO_x emissions to less than 100 parts per million (ppm) and achieves 100 per cent burnout of carbon monoxide with 95-99 per cent overall carbon burnout.

Low NO_X/SO_X Burner Example Installation


Stack Gas Monitoring Equipment
Existing Windbox
Boiler
Baghouse or Electrostatic Precipitator
Flue Gas
Low NO_X/SO_X Burners (Retrofit on Gas, Oil, or Coal-Fired Boiler)
Coal Conveyor
Coal Bunkers
Pulverizers
Slag/Ash
Air Heater
Air
Coal Stockpile

Source: TransAlta Resources Investment Corporation

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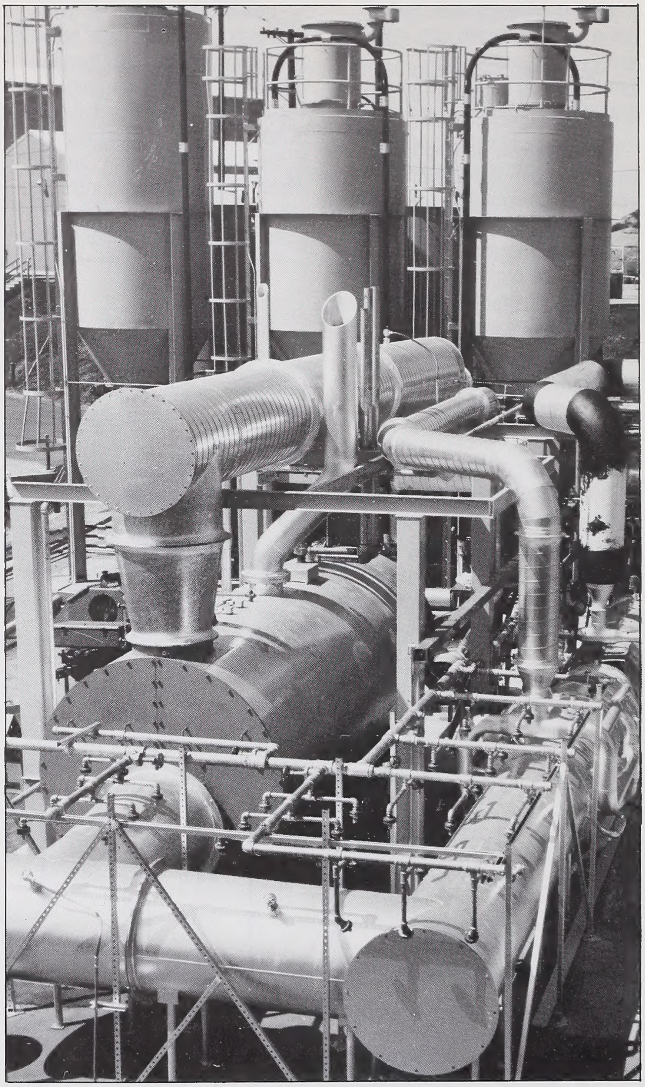
[8] As of June 1989, participants in the Canadian Coal Gasification Technical Committee were: TransAlta Utilities Corporation, Saskatchewan Power Corporation, Shawinigan Integ Inc., Shell Canada Limited, Westar Mining Ltd., Monenco Consultants Limited, Luscar Ltd., Alberta Power Limited, Unocal Canada Limited, Esso Resources Canada Limited, Gulf Canada Resources Limited, Nova Scotia Department of Mines and Energy, Saskatchewan Department of Energy and Mines, Canada Centre for Mineral and Energy Technology (CANMET), and the Alberta Office of Coal Research and Technology, assisted by the Alberta Research Council.

Preliminary studies indicate that the capital cost of equipping coal-fired boilers with LNSBs should be a small fraction of the cost to obtain similar NO_x and SO_x control with state-of-the-art flue gas treatment systems. Also, operating costs should be greatly reduced. Furthermore, incorporation of a slag separator provides the opportunity for retrofit conversion of oil- or gas-fired boilers to coal firing.

Pilot plant testing at 17.9 GJ/h (17 million BTU/hr.) has confirmed the design concept for the LNSB and verified that projected removal efficiencies can be achieved.

In 1986/87, the Alberta Office of Coal Research and Technology provided some financial assistance to complete the pilot-plant tests and to prepare the detailed design of a 105.4 GJ/h (100 million BTU/hr.) commercial-scale demonstration unit.

During 1988, it was suggested that the Low NO_x/SO_x Burner might be ideal for oil field applications, where it would be used to burn coal to produce steam used in heavy oil recovery operations. This concept is particularly attractive because the burner can be retrofitted to current gas-fired steam generators. Therefore, a study was initiated in 1988 to determine the feasibility of installing a LNSB on an existing 52.7 GJ/h (50 million BTU/hr.) steam generator. It would be required to burn low-ash, low-sulphur subbituminous coal, and must also be capable of being scaled up for use on current, commercial-scale heavy oil recovery plants rated at 189.7 GJ/h (180 million BTU/hr.). The demonstration phase of the oil field application is now under way.



Low NO_X/SO_X Burner Test Facility in California

Source: TransAlta Utilities Corporation

Consequently, demonstration-scale and commercial-scale designs were prepared to allow the LNSB to be used with horizontal, once-through steam generators. It is believed these designs can reduce emissions to levels well below current Alberta and Canadian objectives for coal-fired steam generators.

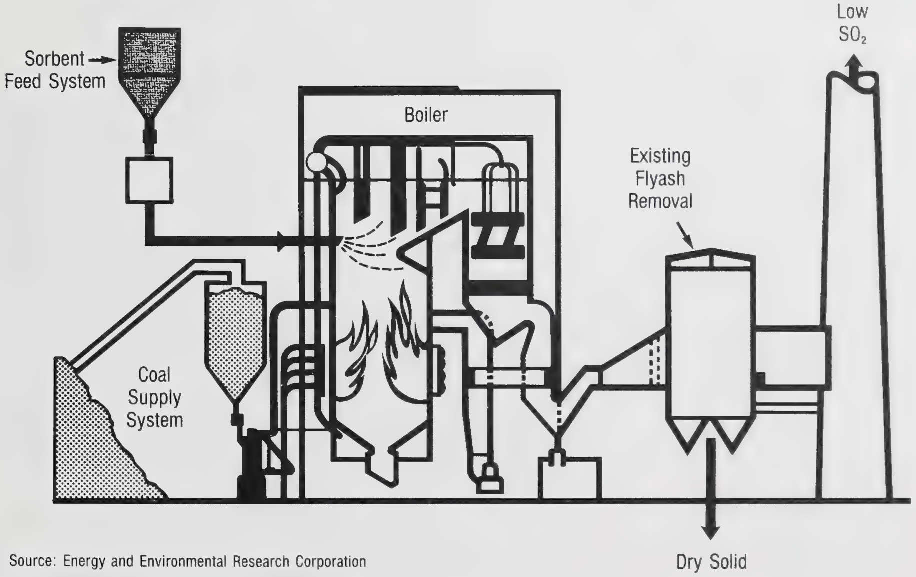
Post-Combustion Technologies

Control of emissions from large-scale sources, such as power plants, can be achieved by post-combustion techniques such as flue gas scrubbing. This particular technology uses alkali solutions to remove sulphur oxides, and ammonia in the presence of a catalyst to reduce chemically the oxides of nitrogen to molecular nitrogen. However, these technologies are not only expensive to install and operate but they also reduce energy efficiency by several percentage points. Consequently, application of these technologies has been resisted in Canada. Several alternative technologies are being developed, however. Some can be retrofitted to existing plants at acceptable cost.

It has been found that some sulphur oxides produced when coal is burned can be captured in the alkali components of coal ash. This has led to the use of alkali sorbents, such as limestone, that are injected into the furnace during combustion. Under optimum operating conditions, tests have shown that 50-70 per cent of the sulphur in some coals (20 per cent in the case of low-sulphur Alberta subbituminous coals) can be captured in this manner.

Although in-furnace limestone (or sorbent) injection technology is a fairly mature technology, it has not attracted much attention because it can meet current Canadian guidelines on plants firing very low sulphur coals only, and cannot meet New Source Performance Standards (NSPS) in the U.S. Sorbent injection, however, can be cost effective when only moderate SO_x capture is required. The technology has been attracting more interest lately as the result of pending acid rain legislation in both the U.S. and Canada. This legislation aims to reduce the overall SO_x and NO_x emissions from existing plants by 50 per cent.

Sorbent Injection



Source: Energy and Environmental Research Corporation

In 1987/88, a Sorbent Injection Technical Committee[9] was established to pursue investigations involving the injection of alkali metal sorbents into coal-fired furnaces to capture acid-forming gases in the form of easily extracted particulates. The committee's principal objective is to establish whether or not sorbent injection is viable for sulphur gas emission control in Alberta.

During 1988, some members of this group sponsored a state-of-the-art review of sorbent injection. The results indicated that sorbent injection techniques have some potential for low-cost SO_2 reduction when used at existing power plants. It was recommended that bench-scale tests of Alberta coals and locally available sorbents should be undertaken to determine the best combinations for Alberta's coal-fired electricity-generating plants.

Although the sulphur content of some Alberta subbituminous coals is sufficiently low that current, new-source emission regulations can be met without sulphur oxide emission control, it was recognized that this does not apply to all Alberta subbituminous coals. Therefore, some degree of flue gas clean-up or control will be required to satisfy existing regulations and meet even more stringent guidelines that might be introduced later for sulphur oxide and nitrogen oxide emissions.

During 1987/88, the Alberta Office of Coal Research and Technology provided partial funding for a study of several in-furnace and post-combustion emission-control technologies that might be used in Alberta.

It was concluded that the most cost-effective approach to emission control would be to use in-furnace technology as much as possible, and supplement it with post-combustion control if emission standards become even more stringent in the future. Depending on coal quality, it was predicted that NO_x and SO_x emissions would range from 50 to 100 per cent of currently regulated limits for new coal-fired sources using in-furnace technology.

For the present, it was recommended that a combination of furnace sorbent injection and multi-stage burners be used. Several add-on technologies were suggested in the event of more stringent standards.

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[9] Committee members as of June 1989 were: Esso Resources Canada Limited, Edmonton Power, TransAlta Utilities Corporation, Alberta Power Limited, Luscar Ltd., Monenco Consultants Limited, and the Alberta Office of Coal Research and Technology.

Coal Combustion Science

Emissions of NO_x are produced from two sources during coal combustion: from the nitrogen contained in the fuel, and from fixation of atmospheric nitrogen in the hotter parts of the flame. A large portion of it can be converted to molecular nitrogen by controlling the manner in which air is added during combustion. The mechanisms involved in these conversions are the subject of some coal-combustion investigations being carried out by the International Energy Agency in The Netherlands. The Alberta Office of Coal Research and Technology is participating in these studies on behalf of Alberta coal producers to obtain comparative information on the combustion performance of selected Alberta coals relative to other internationally traded coals. A second objective is to acquire knowledge about the use of low-rank Alberta coals for power generation and other applications.

The research program is investigating the following mechanisms: nitrogen oxides formation during pulverized coal combustion and opportunities for their reduction through staged combustion; sulphur oxides formation and reduction by the use of direct sorbent injection; transformation of mineral matter during combustion in relation to combustion system slagging, fouling and fly ash emissions; and combustion of various types of coal from several sources. The study is also developing methods of predicting flame characteristics.

Carbon Dioxide

It is encouraging to note that integrated gasification combined cycle systems, now being developed as future power generation systems, use fuel more efficiently than conventional power plants to produce electricity. For example, some gasification systems have efficiency ratings of 50 per cent versus approximately 33 per cent for conventional electricity-generating stations. This means that less coal is used to produce the same amount of electricity, and less CO_2 is produced as a by-product.

While it has been argued that certain activities, such as power generation, contribute little CO_2 to the world total and, therefore, little justification exists to take corrective action, it must also be noted that the imbalance in the world's CO_2 cycle is being caused by man. Currently, no one knows with any certainty how much man-made CO_2 is too much, but it must be assumed that contributions from one source or another, no matter how small, are not insignificant. Conversely, it is equally unfair to single out one source as a primary cause when the situation calls for concerted efforts on many fronts. With this in mind, and with coal research being the primary interest of the Alberta Office of Coal Research and Technology, action is being taken to determine which clean coal technologies options offer the best chances of both reducing SO_2 and NO_x emissions and allowing reductions in CO_2 release to the atmosphere.

Clean Coal Research Projects

Completed or Under Way in Alberta

Project	Principal Performer	Status
Gasification of Western Canadian Coals	TransAlta Utilities Corporation	Completed in 1986/87
Fluidized Bed Gasification of Highvale Coal	TransAlta Utilities Corporation	Completed in 1987/88
Economics of Coal Gasification	Alberta Power Limited	Completed in 1987/88
IGCC Utility Applications	TransAlta Utilities Corporation	Continuing
Gasification Process Research	Alberta Research Council	Completed in 1987/88
Gasification Properties of Alberta Coals	Alberta Research Council	Completed in 1987/88
Gasification Behaviour of Alberta Coals	Alberta Research Council	Completed in 1988/89
Gasification Laboratory Facilities	Alberta Research Council	Completed in 1987/88
Devolatilization Properties of Alberta Coals	Alberta Research Council	Continuing
Gasification Properties of Alberta Coals, II	Alberta Research Council	Continuing
Low NO_x/SO_x Burner	TransAlta Utilities Corporation	Completed in 1986/87
Application of the LNS Burner to an Oil Field Steam Generator	TransAlta Resources Investment Corporation	Completed in 1988/89
LNS Burner Steam Generator Demonstration	TransAlta Resources Investment Corporation and Esso Resources Canada Limited	Continuing
Coal for Use in Enhanced Oil Recovery: Emission Control Technology	Esso Resources Canada Limited	Completed in 1987/88
Sorbent Injection Study	Alberta Power Limited	Completed in 1988/89
International Energy Agency Basic Coal Combustion Science	Netherlands Energy Research Foundation ECN	Completed in 1988/89
Extension to International Energy Agency Annex II Basic Coal Combustion Science	Netherlands Energy Research Foundation ECN	Continuing

Further Information

Persons requiring more information about clean coal technologies suitable for Alberta, should contact:

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ISBN 0-86499-621-7
Pub. No. I/279